31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Testing an In-Home Gait Assessment Tool for Older Adults

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Abstract— **In this paper, we present results of an automatic vision-based gait assessment tool, using two cameras. Elderly residents from TigerPlace, a retirement community, were recruited to participate in the validation and test of the system in scripted scenarios representing everyday activities. The residents were first tested on a GAITRite mat, an electronic walkway that captures footfalls, and with inexpensive web cameras recording images. The extracted gait parameters from the camera system were compared with the GAITRite; excellent agreement was achieved. The residents then participated in the scenarios, with only the cameras recording. We found that the residents displayed different gait patterns during the realistic scenarios compared to the GAITRite runs. This finding provides support of the importance and advantage of continuous gait assessment in a daily living environment. Results on 4 elderly participants are included in the paper.**

I. Introduction

As more and more senior persons continue to prefer living independently in unrestricted environments, the demand for continuous assessment of their daily activities and detecting signs of their functional decline continues to rise [1]. Falls are a major cause of morbidity among the elderly and in almost all incidences of falls some aspects of locomotion have been implicated. With the increased life expectancy of the elderly and their more active lifestyle there is now an emphasis on determining any changes that occur in their gait patterns in order to reduce the frequency of falls, to identify diagnostic measures that are predictors of fall-prone elderly, and finally to develop programs for preventing such falls [2].

While monitoring the regular day-to-day activities of the elderly, we realized that it could be extremely beneficial to study their gait, as walking is one of the most natural physical activities and can be conveniently and easily accommodated into an older adult's routine. Studies have supported the significance of walking speed in the assessments of physical function in the elderly [3]. Thus, monitoring older adults' walk using certain smart-home technologies, such as camera monitors and walking sensors, on a daily basis can provide essential information on the changes of functional status, and therefore effective strategies can be implemented in a timely manner to prevent or reduce severe negative outcomes. Extensive research has been conducted on low-cost vision-based systems for monitoring and assessing daily activities of the occupants. In [4], work was presented to detect sit to stand strategies associated with balance impairment using a web camera. The long term goal is to create systems that can monitor functional movements common at home in a way that reflects changes in stability and impairment. In [5], the UbiSense system is proposed to capture signs of deterioration by analyzing small changes in posture and walking, in addition to monitoring normal daily activities and detecting potentially adverse events such as falls. In [6], an indoor posture classification method is discussed using a multi-camera system for monitoring people in domestic environments.

In our work, we are assisted by volunteer elderly residents at TigerPlace, a retirement community with the aim to help residents age in place, stay active and healthy and for most, avoid a move to a nursing home. A key feature of TigerPlace is making available cutting-edge research opportunities for residents who choose to participate. Such research includes evaluating the effectiveness of technology to help seniors with common problems of aging such as mobility, cognitive, and/or sensory impairments [7]. The long-term goal of our project is to generate alerts that notify care givers of changes in a resident's condition so they can intervene and prevent or delay adverse health events [8].

II. Study Overview

A. Experimental Setup

Ten residents at TigerPlace were recruited to participate in a test and validation of a multi-camera system for gait assessment. The age of the participants ranges from 81 to 94 years old. Some of them walk independently and some use a walker, cane or wheelchair. The assistive devices impose more challenges to the gait analysis. All participants are managing a chronic medical condition; some have a history of falling. Due to space limitations, we will describe the results of 4 participants who are typical of the group. The residents were first tested on the GAITRite system (see section II-B), to establish ground truth for the camera system, as well as to provide baseline gait information.

All volunteers then participated in two scripted scenarios with realistic daily activities. The scenarios involve a two person environment and are designed to include common everyday activities that also provide the type of information needed to assess physical function of older adults.

Manuscript received April 7, 2009. This work was supported in part by the U.S. National Science Foundation under Grant IIS-0703692.

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The first scenario is the *visitor* scenario, in which the resident is sitting in a chair in the living room, and a visitor walks into the room to the chair, bends and greets the resident with a hug, then sits on the couch nearest the resident for two minutes as they talk. The resident then stands up and walks to the kitchen, opens the cabinet, and reaches for a cup and tea. He/she pours water into the cup, opens the microwave, and places the cup inside. The resident and the visitor chat as they wait for the tea. The resident then walks back and hands the cup to the visitor. They both sit while the visitor drinks the tea. The visitor then rises from the couch, approaches the side of the chair where the resident is sitting and helps the resident to stand (if assistance is needed). The resident walks to the door, puts on a jacket, and opens the door. The visitor exits and the resident follows.

The second scenario is the *housekeeping* scenario. In this scenario, an active resident enters the room from grocery shopping. He/she reaches up to open a cabinet, places groceries in, and then walks across the living room, bends and picks up newspapers on a table, walks across the room to the kitchen recycling receptacle and places them in the receptacle. After pausing briefly, he/she walks back to the living room and opens the door. A housekeeper enters with cleaning supplies. The housekeeper takes some supplies and begins cleaning. The resident sits in the chair and reads for a minute, and then leaves the room. The housekeeper leaves the room after a minute.

The scenarios are explained to each volunteer resident in detail before the recording. A research team member plays the visitor or housekeeper role and is present to provide step by step instructions during the data collection. The residents are not required to memorize any step. Volunteer residents are given gift cards for their participation and seem to enjoy their roles as paid actors.

B. GAITRite

The GAITRite system [9] (available commercially from CIR Systems Inc.) used in the experiment is an electronic mat with an effective length of 16 feet, formed by 8 sensor pads connected to each other. Each sensor pad has an active area of 24 inches square (61cm square) and contains 2,304 sensors arranged in a (48x48) grid pattern. The sensors are placed 1.27 cm apart and are activated by mechanical pressure. Footfall data from the activated sensor is collected by a series of on-board processors and transferred to the computer through a serial port. Using the footfall patterns, the temporal (timing) and spatial (distance) parameters are derived. The sampling rate of the system is 120Hz.

C. Camera system

The camera system consists of two inexpensive web cameras (Unibrain Fire-i Digital Cameras), placed approximately orthogonal to each other. The cameras captured video at a rate of 5 frames per second, with a picture size of 640x480 pixels. Black and white silhouettes were extracted from the raw videos to maintain the privacy of the residents.

The silhouettes were further preprocessed before the gait parameters were extracted. This involved filtering the images using median filters to remove noise and then further convoluting the image with masks to smooth the images and reduce the number of connected components. The morphological opening operations were also applied on the images to remove the small holes in the foreground. We used color information to separate the two people and associate a person in one camera image with the corresponding person in the second camera image.

By back projecting silhouettes from two camera views, the three-dimensional human model, called voxel person, described and used in [10], is constructed in voxel (volume element) space. A semi-automated camera calibration was introduced to speed the calibration process and obtain accurate voxel reconstructions. An intrinsic model of each camera is estimated using the Camera Calibration Toolbox from [11]. A set of fixed architectural features (e.g., door frames) is measured in the environment and associated with pixel locations as part of the calibration process. This calibration procedure results in significantly more accurate voxel person reconstructions as compared to the previous technique. Here, the voxel resolution is 1x1x1 inch.

The gait parameters studied include walking speed, step time and step length. The detailed extraction procedure can be found in [12]. The method is summarized as follows: the distance a participant traveled is approximated by adding up the voxel centroid change from each frame. The number of steps is extracted from a person's feet spread and close pattern while walking. Time information is obtained from frame numbers. Therefore, the walking speed is calculated by walking distance divided by walking time, and average step time is calculated by walking time divided by number of steps. Average step length can be calculated as a product of walking speed and step time. The work described in [12] outlines the validation conducted in a lab setting with research team members. Here, the work is taken out of the lab into a less structured setting with elderly volunteers.

III. RESULTS

A. Validation with GAITRite

The two-camera based gait analysis system has previously been validated in the lab with gait analysis tools including GAITRite and Vicon systems for different gait patterns [12]. Excellent agreements have been achieved for gait parameters studied. These tests were all conducted in the lab with research team members. In order to further validate the system in more realistic daily living settings, we conducted the following experiments in TigerPlace with elderly resident participants. Participants walked on the GAITRite mat while cameras recorded images, as shown in Figure 1. The silhouettes were extracted from the raw images (Figure 1b). Figure 1c shows the 3D reconstructed voxel person (1x1x1 inch resolution).

Table I presents four typical examples of results for gait parameters extracted from images compared with the GAITRite system. Participant 1 uses a cane. They are very well matched, considering the camera frame rate and voxel person resolution. These results have given us confidence in the camera system performance and accuracy in a realistic daily environment.

Besides the one GAITRite test listed in Table I, each participant has normally 4 consecutive tests done on the GAITRite. We have observed an interesting trend for all the participants that their walking speed gradually increases as the GAITRite tests progress. The reason might be that they are becoming more familiar and confident in walking on the GAITRite carpet.

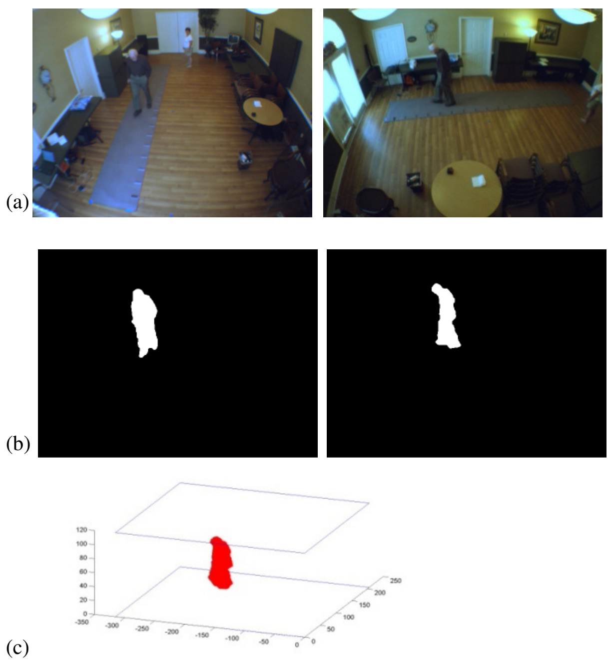

Fig.1. Resident walking on the GAITRite mat. (a) Two cameras monitoring the same scene. (b) Extracted human silhouettes. (c) Three dimensional voxel person reconstructed from the silhouettes.

Table I. Cameras (cam) compared with GAITRite (GR)

	Participant 1		Participant 2		Participant 3		Participant 4	
	cam	GR	cam	GR	cam	GR	cam	GR
Walk speed (cm/s)	79.8	80.5	77.3	77.1	74.6	76.9	63.6	63.4
Step time (s)	0.66	0.68	0.58	0.57	0.67	0.65	0.7	0.7
Step length (cm)	52.5	54.3	45.0	44.1	49.7	49.6	44.5	44.2

B. Gait assessment with realistic scenarios

We manually segmented the scenario videos to obtain sections in which the participant has a continuous walking distance with a minimum of 4 steps. One example (*Participant 1, walk2*) is shown in Figure 2. The walking trajectory in 2 dimensional space is plotted in Figure 2(b). The points represent the centroid locations of the voxel person in each frame. The participant started walking from point A and ended in point B. The total walking distance is 160.7cm, finished with 4 step cycles. The walk path apparently is not a straight walk. By using multiple cameras to reconstruct the 3D voxel person, the system and algorithm are designed to handle such a situation properly. Some voxel person examples are shown in Figure 2(a).

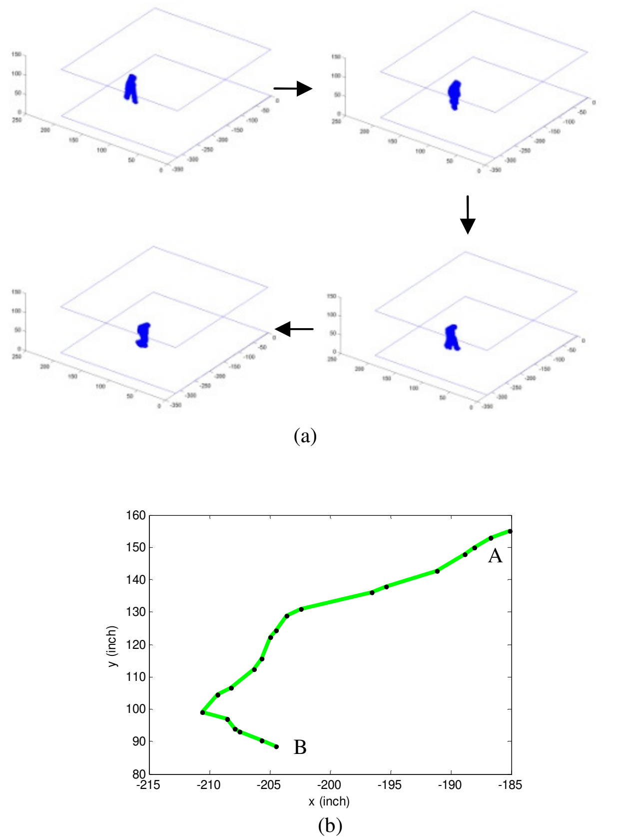

Fig. 2. Resident in realistic scenario. (a) Sample voxel persons in sequence (b) Walking trajectory projected in 2D space. Each point represents the centroid location in a frame.

In the following section, the cases of the four participants are presented. The gait parameters extracted from the scenario are compared with the participant's GAITRite results. As mentioned earlier, the GAITRite tests are done separately from the scenarios, and results listed below are obtained from the average of normally four consecutive GAITRite runs in order to account for the gait variations the participants have displayed.

Participant 1:

The two walks from the scenario took place in two different locations on different dates. It has been observed that the walking speed for this participant is consistently lower than the GAITRite results. The participant also consistently strides slower and with smaller step lengths compared to the GAITRite runs.

	Walk1	Walk2	GAITRite
Walking speed(cm/s)	59.5	53.6	84.8
Step Time(s)	0.80	0.75	0.65
Step Length(cm)	47.6	40.2	54.7

Participant 2:

Similar to participant 1, the two walks from the scenario also took place in two different locations on different dates. The participant walked slightly slower in the scenario compared to the GAITRite runs.

	Walk1	Walk2	GAITRite
Walking speed(cm/s)	67.2	68.2	74.2
Step Time(s)	0.65	0.60	0.58
Step Length(cm)	43.7	40.9	42.8

Participant 3:

Only one walk was obtained for this participant. Similarly, the participant walking speed in the scripted scenario is lower than when tested on the GAITRite, with a faster stride rate and a smaller step length.

	Walk1	GAITRite
Walking speed(cm/s)	57.8	74.2
Step Time(s)	0.70	0.67
Step Length(cm)	40.4	49.7

Participant 4:

The results for this participant displayed a different pattern from the previous three participants. Walk2 and walk3 are taken from the same scenario, only minutes apart, while walk1 is at a different location on a different date. It is interesting to notice that walk2 is different from walk1 and walk3 in terms of speed and step time. The participant walks much faster in walk2 compared to all other walks, including on the GAITRite. Some factors might contribute to the difference. One of them is the walking purpose. In walk2, the participant is going towards a table to pick up a newspaper, and in walk2, the participant is going towards a trash can to discard the newspaper. In addition, walk2 (198cm) has a longer walk distance than walk1 (146cm) and walk3 (137cm).

	Walk1	Walk2	Walk3	GAITRite
Walking speed(cm/s)	66.6	82.7	62.4	70.2
Step Time(s)	0.73	0.60	0.73	0.67
Step Length(cm)	48.8	49.6	45.8	46.8

In normal everyday activities, three participants have displayed different walking patterns compared to the GAITRite runs. They all consistently walk slower, with a slower step rate in the scenario. When considering the difference, one factor may be that the walking distance in the scenario is usually shorter than the GAITRite 16 ft (508.8cm) test length that one can use to accelerate. Another factor might be also due to the Hawthorne effect which is a form of reactivity wherein subjects improve the aspect of their behavior while being measured simply in response to the fact that they are being watched, not in response to any particular experimental manipulation [13] [14]. And we have observed inconsistent results with the fourth participant.

IV. SUMMARY

We have presented a practical gait assessment tool, which has been tested in a senior housing environment with volunteer residents. Through the study, we have found that the participants displayed different gait patterns in the realistic in-home scenarios than when tested on the GAITRite mat. This provides further support of the importance and necessity to have an in-home daily gait assessment tool that can monitor the older adults' gait continuously. The in-home environment is expected to be more challenging than the lab setting due to the complexity of the real world environment. Our future research interests include automatic segmentation of the video sequences to identify the walking sequences that are suitable for gait analysis, multiple person tracking and identification, and silhouette extraction with variable lighting conditions.

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